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(57) Abstract

The methods of the invention can be used to treat mycobacterial infections, or any disease or disorder that is caused by (or aggravated by) an intracellular pathogen. Accordingly, the invention features methods for treating a subject who has a disorder that is associated with an intracellular pathogen by administering, to a subject, a molecular conjugate that includes a photosensitizer (a term used herein to refer to a light activatable compound) and a targeting moiety, the targeting moiety being capable of targeting the conjugate to the intracellular pathogen.

(57) Abrégé

Les méthodes de l'invention peuvent être utilisées pour traiter des infections mycobactériennes ou n'importe quelle maladie ou trouble provoqués (ou aggravés) par un agent pathogène intracellulaire. Par conséquent, l'invention présente des méthodes de traitement d'un sujet présentant un trouble associé à un agent pathogène intracellulaire par administration audit sujet d'un conjugué moléculaire contenant un photosensibilisant (un terme utilisé ici pour faire référence à un composé photoactivable) et une fraction ciblante, la fraction ciblante étant capable de cibler le conjugué sur l'agent pathogène intracellulaire.

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(71) Applicant: THE GENERAL HOSPITAL CORPORATION [US/US]; 55 Fruit Street, Boston, MA 02110 (US).

(72) Inventors: HASAN, Tayyaba; 61 Hillside Avenue, Arlington, MA 02476-5834 (US). GROSS, Jerome; 77 Dorset Road, Waban, MA 02468-1455 (US). NAU, Gerard, J.; 17 R Gorham Street, Somerville, MA 02144-2704 (US).

(74) Agent: MYERS, Louis; Fish & Richardson P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).

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Description

PHOTOSENSITIZER CONJUGATES FOR TARGETING INTRACELLULAR PATHOGENS

This application claims the benefit of U.S. provisional application serial no. 60/104,584, filed October 16, 1998, and U.S. provisional application serial no. 60/115,976, filed January 15, 1999, which are hereby incorporated by reference in their entirety.

Background of the Invention

The invention relates to a molecular conjugate that includes a photosensitizer and a targeting moiety, and to methods of using the conjugate.

Infectious diseases continue to generate substantial medical problems. This is due, in part, to the emergence of strains of bacteria that are resistant to multiple antibiotics, newly discovered viral diseases, and the spread of diseases caused by fungi and protozoa. For example, the recent emergence of multi-drug resistant strains of *Mycobacterium tuberculosis*, the underlying cause of tuberculosis, is generating a public health problem of epic proportion. Computer modeling studies and field surveys of geographically isolated human communities indicate that tuberculosis may become endemic in host populations having as few as 200 contiguous individuals (a dramatic contrast with diseases such as measles and smallpox, which are maintained only within communities having more than 200,000 contiguous individuals). Moreover, the immune response to *M. tuberculosis* is not eradicative; infected individuals may develop lifelong chronic diseases or latent infections that serve as long-standing reservoirs of contagion.

Summary of the Invention

Many serious infectious diseases are characterized by the ability of a pathogenic organism to invade and reproduce within the cells of a host organism (the host being referred to herein as "the subject"). Mycobacteria, which behave in this manner, are responsible for tuberculosis, leprosy, MAI complex infection in AIDS patients, and other diseases (such as Buruli ulcer).

Following infection, mycobacteria are phagocytosed by macrophages where they are "sheltered" from many antibiotic drugs and from the subject's immune system. This is especially true in pulmonary tuberculosis, where infected macrophages gather in intrapulmonary granulomas.

The methods of the invention can be used to treat mycobacterial infections, or any disease or disorder that is caused by (or aggravated by) an intracellular pathogen. Accordingly, the invention features methods for treating a subject who has a disorder that is associated with an intracellular pathogen by administering, to the subject, a molecular conjugate that includes a photosensitizer (a term used herein to refer to a light activatable compound) and a targeting moiety, the targeting moiety being capable of targeting the conjugate to the intracellular pathogen. In one embodiment, the subject is treated with a conventional therapy (such as an antibiotic-based therapy) and a molecular conjugate that includes a photosensitizer and a targeting moiety. The targeting moiety is so named because it can target the conjugate to the intracellular pathogen or to the infected host cell (*e.g.*, a macrophage).

Accordingly, the invention features a method for treating a subject having a disorder associated with an intracellular pathogen that includes administering to the

subject an antibiotic and a molecular conjugate (which can include a photosensitizer or a photosensitizer and a targeting moiety that targets the conjugate to the intracellular pathogen). The molecular conjugate can be administered before, during, or after the antibiotic is administered. As in other embodiments, the intracellular pathogen can be a bacterial cell (such as a mycobacterium, *e.g.*, *Mycobacterium tuberculosis*). The pathogen can be within a phagocyte (*e.g.*, a macrophage). The method can also include irradiating the subject, preferably using a wavelength that causes the photosensitizer to produce a cytotoxic effect. Preferably, the cytotoxic effect is substantial enough to kill at least 50%, more preferably at least 70%, and most preferably at least 90% of the pathogenic cells. The source of the irradiation can be any of the sources described herein, for example, a laser.

In another embodiment, the invention features a method for killing a Mycobacterial cell by contacting the cell with a molecular conjugate that includes a photosensitizer and irradiating the cell with light having a wavelength that causes the photosensitizer to produce a cytotoxic effect. The method can further include administering a molecular conjugate that includes both a photosensitizer (*e.g.*, a porphyrin or an active derivative thereof) and a targeting moiety that targets the conjugate to an infectious agent (*e.g.*, a polypeptide, such as transferrin). The subject is irradiated with light, preferably using a wavelength that causes the photosensitizer to produce a cytotoxic effect. Preferably, the cytotoxic effect is substantial enough to kill at least 50%, more preferably at least 70%, and most preferably at least 90% of the pathogenic cells. The source of the irradiation can be any of the sources described herein, for example, a laser.

In another embodiment, the invention features a method of treating a subject having an infectious disease of the lung by administering to the subject a molecular conjugate that includes a photosensitizer (*e.g.*, porphyrin or an active derivative thereof) and irradiating the lung with light having a wavelength that causes the photosensitizer to produce a cytotoxic effect. The molecular conjugate can also include a targeting moiety that targets the conjugate to an infectious agent (*e.g.*, a polypeptide, such as transferrin). Those of skill in the art will recognize that the infectious disease of the lung can be associated with a bacterial infection (*e.g.*, an infection associated with a *Mycobacterium* such as *M. tuberculosis*). In this or other methods described herein, the irradiation can be directed to the source of the infection. For example, in the event of a pulmonary infection, irradiation of the lung can be provided by a light source introduced into the passages through which air is inhaled. Alternatively, the irradiation of the lung can be provided by a light source introduced through the chest wall. Similarly, irradiation can be directed to particular regions of the body or particular parts of an organ or tissue. For example, in the event of a pulmonary infection, irradiation of the lung can be directed to the base of the lung, to the apex of the lung, or both.

The term "subject" is used herein to refer to a living animal, including a human, that carries an unwanted organism, the unwanted organism being the target of the therapeutic methods described herein. Accordingly, the unwanted organism may be referred to as the "target organism". The subject can be a mammal, such as a human or a non-human mammal (*e.g.*, a dog, cat, pig, cow, sheep, goat, horse, rat, or mouse). The subject may be immune deficient; presently or previously undergoing

treatment for cancer (*e.g.*, by chemotherapy or radiation therapy); or presently or previously undergoing antibiotic therapy or an immunosuppressive therapy.

The intracellular pathogen may be contained within a host cell, such as a phagocyte (*e.g.*, a macrophage). Further, within that cell, the pathogen may be contained (wholly or partly) within a vacuole, vesicle, or organelle.

Those of ordinary skill in the art will recognize disorders (or diseases or conditions) amenable to treatment with the present methods. The treatment may be effectively applied in the event a subject has a disease that is in a latent or an active stage. More specifically, disorders, diseases, or conditions amenable to treatment include, but are not limited to, tuberculosis and other disorders characterized by intrapulmonary granulomas, leprosy, MAI complex infections in AIDS patients, leishmaniasis and toxoplasmosis.

Once a molecular conjugate of the invention has been administered, the subject can be treated with irradiation. Typically, the irradiation (such as that generated by a laser) will have a wavelength that causes the photosensitizer (a part of the conjugate) to produce a cytotoxic effect (*e.g.*, generation of toxic oxygen species, which can diffuse through the bacterial cell wall, or generation of reactive nitrogen intermediates). The photosensitizer can be a porphyrin or an active derivative thereof (*i.e.*, a porphyrin that retains at least 50%, more preferably at least 80% (*e.g.*, 85% or 90%), and most preferably at least 95% of the cytotoxic activity of the porphyrin from which it was derived). Assays by which this activity can be assessed are described further below. The photosensitizer can be chlorin e6.

To increase the specificity of the photosensitizer for its target, the photosensitizer may be bound to a targeting moiety. The targeting moiety can be a polypeptide (*e.g.*, a human polypeptide such as poly-lysine or serum albumin). Alternatively, the targeting moiety can be a small anti-microbial peptide (*i.e.* a peptide containing less than 60 amino acid residues).

Also described further below are considerations relevant to administering the conjugate. These include routes of administration, including intravenous and parenteral (*e.g.*, topical) administration. The conjugate can be administered to the lung in a variety of ways. For example it can be administered by way of the passages through which air is inhaled (*i.e.*, it can be administered intratracheally, intrabronchially, or intraalveolarly). Alternatively, the conjugate can be administered through the body wall of the chest. The light that is applied to the conjugate once it has been administered can be applied through these routes as well (*e.g.*, a light source, or a portion thereof, can be placed within the trachea, bronchi, or bronchioles of the lung or it can be inserted through the chest wall). The molecular conjugate may be administered to a subject on more than one occasion (*i.e.*, at least twice). Similarly, a conjugate that has been administered can be illuminated on more than one occasion (*i.e.*, at least twice), and the illumination (or irradiation) can be directed to the base of the lung, the apex of the lung, or both.

The invention also encompasses methods for making conjugate molecules, for example, by coupling a targeting moiety to a photosensitizer. The conjugate may further include a backbone to which both the targeting moiety and photosensitizer are coupled. The coupling reactions can involve an activated ester moiety of a photosensitizer.

Alternatively, an amino group on the backbone may react as a nucleophile, displacing the leaving group from the photosensitizer active ester. Preferably, the targeting moiety is coupled to the backbone with a coupling agent.

In some embodiments, the conjugate does not include (*i.e.*, it is not coupled, either covalently or non-covalently, to) an antibody, an enzyme, a hormone, a receptor on a cell surface, or the ligand for a receptor on a cell surface. However, in other embodiments, the conjugate can include (*i.e.*, it can be coupled, either covalently or non-covalently, to) an antibody, an enzyme, a hormone, a receptor on a cell surface, or the ligand for a receptor on a cell surface.

Compositions of the invention are advantageous in that (i) they do not need to be internalized to bacteria to kill bacteria, (ii) the generation of toxic species (*e.g.*, reactive oxygen intermediates or reactive nitrogen intermediates) can have a local effect in stimulating the host immune response, which in turn assists in eradicating bacteria and in promoting healing of the wound, and (iii) they produce a cytotoxic response only in the area subject to illumination.

Brief Description of the Drawings

Fig. 1 is a bar graph representing the number of colony forming units (CFU/ml) formed by cells exposed to various molecular conjugates (specified along the Y axis) and then to light (L) or dark (D).

Figs. 2A - 2C are bar graphs representing the fraction of cells that survived following exposure to the molecular conjugates described along the X axis (Fig. 2A), the uptake of each of the molecular conjugates (Fig. 2B), and the resulting relative phototoxicity (Fig. 2C).

Detailed Description

A. Molecular Conjugates

The invention features molecular conjugates that include a photosensitizer coupled to a targeting moiety.

1. The photosensitizer

A photosensitizer is a substance that produces a cytotoxic effect when irradiated with electromagnetic energy of an appropriate wavelength. Typically, a photosensitizer will be irradiated with light of an appropriate wavelength.

Many photosensitizers produce singlet oxygen. Upon electromagnetic irradiation at the proper energy level and wavelength, the photosensitizer is converted to an energized form that can react with atmospheric oxygen such that, upon decay of the photosensitizer to the unenergized state, singlet oxygen is produced. Singlet oxygen is highly reactive and is toxic to a proximal target organism, as are reactive nitrogen intermediates.

A molecular conjugate containing a photosensitizer should efficiently absorb electromagnetic energy of the appropriate wavelength with high quantum yield to efficiently generate the energized form of the photosensitizer. Toxicity to the target organism should increase substantially, preferably 10-fold, 100-fold, or even 1,000-fold upon irradiation. Ideally, a photosensitizer should exhibit low background toxicity, *i.e.*, it should not be toxic in the absence of irradiation with energy of the appropriate wavelength. Further, a photosensitizer of the invention should be readily soluble in a variety of solvents, including those in which it is coupled to the targeting moiety and those in which it is administered to a subject. Those of ordinary skill in the art will recognize that what is desirable in the context of solubility will differ depending on the conditions in which the photosensitizer

is coupled to form a conjugate (or the conditions in which the conjugate is administered). For example, the photosensitizer and targeting moiety may be coupled in a reaction requiring solubility in DMSO, water, ethanol, or a mixture thereof (*e.g.*, a 1:1 mixture of DMSO:H_2O or 5% ethanol in water).

Photosensitizers include, but are not limited to, hematoporphyrins, such as hematoporphyrin HCl and hematoporphyrin esters (Dobson *et al.*, *Arch. Oral Biol.* 37:883-887); dihematophorphyrin ester (Wilson *et al.*, *Oral Microbiol. Immunol.* 8:182-187, 1993); hematoporphyrin IX and its derivatives (Russell *et al.*, *Can. J. App. Spectros.* 36:103-107, available from Porphyrin Products, Logan, UT); 3,1-meso tetrakis (*o*-propionamidophenyl) porphyrin; hydroporphyrins such as chlorin, herein, and bacteriochlorin of the tetra (hydroxyphenyl) porphyrin series, and synthetic diporphyrins and dichlorins; *o*-substituted tetraphenyl porphyrins (picket fence porphyrins); chlorin e6 monoethylendiamine monamide (CMA; Goff *et al.* 70:474-480, 1994; available from Porphyrin Products, Logan, UT); mono-1-aspartyl derivative of chlorin e6, and mono- and di-aspartyl derivatives of chlorin e6; the hematoporphyrin mixture Photofrin II (quardra Logic Technologies, Inc., Vancouver, BC, Canada); benzophorphyrin derivatives (BPD), including benzoporphyrin monoacid Ring A (BPD-MA), tetracyanoethylene adducts, dimethyl acetylene dicarboxylate adducts, Diels-Adler adducts, and monoacid ring "a" derivatives; a naphthalocyanine (Biolo, *Photochem and Photobiol.* 5959:362-365, 1995); toluidine blue O (Wilson *et al.*, *Lasers in Medical Sci.* 8:69-73, 1993); aluminum sulfonated and disulfonated phthalocyanine ibid.; and phthalocyanines without metal substituents, and with varying other substituents; a

tetrasulfated derivative; sulfonated aluminum naphthalocyanines; methylene blud (ibid.); nile blue; crystal violet; azure β chloride; and rose bengal (Wilson, *Intl. Dent. J.* 44:187-189, 1994). Numerous photosensitizer entities are disclosed in Wilson *et al.*, (*Curr. Micro.* 25:77-81, 1992) and in Okamoto *et al.* (*Lasers in Surg. Med.* 12:450-485, 1992).

Other potential photosensitizer compositions include but are not limited to, pheophorbides such as pyropheo-phorbide compounds, anthracenediones; anthrapyrazoles; aminoanthraquinone; phenoxazine dyes; phenothiazine derivatives; chalcogenapyrylium dyes including cationic selena- and tellura-pyrylium derivatives; verdins; purpurins including tin and zinc derivatives of octaethylpurpurin and etiopurpurin; benzonaphthoporphyrazines; cationic imminium salts; and tetracyclines.

The suitability of a photosensitizer for use in a conjugate can be determined by methods described herein or by methods known to those skilled in the art.

The efficiency with which a photosensitizer oxidizes a target molecule is a measure of its usefulness. The efficiency of the oxidation of a target molecule by a photosensitizer can be determined *in vitro*. Examples of substrates include 4-nitroso-N, N-dimethylaniline (RNO; Hasan, *et al.*, *Proc. AACR* 28:395 Abstr. 1,568, 1987), and tryptophan or histidine (Lambert et al., *Photochem. Photobiol.* 44:595-601, 1986). In these assays, the ability of a candidate photosensitizer to "bleach" the substrate can be monitored spectroscopically. The advantage of a chemical assay is that a large number of putative photosensitizer compositions can be simultaneously screened. Parameters that can be varied include photosensitizer concentration, substrate concentration, optimal intensity of

irradiation, and optimal wavelength of irradiation. High through-put technologies including plastic multi-well dishes, automated multi-pipetters, and on-line spectrophotometric plate readers can be used. Undesirable candidates, for example, compositions having high backgrounds under unirradiated conditions, inefficient energy capture or reactive potential, can be identified and eliminated.

In vivo assays with cells of one or more model target organisms can be used to evaluate a photosensitizer for cytotoxicity of its background and activated forms. The efficiency of killing of the organism in the presence of the irradiated and unirradiated photosensitizer can be measured and compared to survival of the untreated control cell sample. This assay can be automated. The use of counts of colony forming units (CFU) or cell growth may require incubation of the samples that have been applied to a nutrient medium, with a concomitant lag of the appropriate growth period to allow for colony formation.

Survival of cells of the model target organism can alternatively be monitored by assay of a biochemical process, for example, assay of DNA synthesis. In this approach, the effectiveness of a photosensitizer candidate can be measured by its effect on samples of cells of the model organism, which are also exposed to a labeled DNA precursor such as tritiated thymidine. Cells are then collected, washed to remove unincorporated precursor, and monitored for uptake of the precursor and incorporation into acid-insoluble precipitate, which is a measure of quantity of DNA synthesis. In this assay, which can also be automated, quantitative evaluation of the effects of presence of irradiated photosensitizer compositions can be readily evaluated and quantitated. In control unirradiated cells and in untreated cells, DNA

synthesis increases logarithmically as a function of cell growth. A positive result indicating presence of a putative successful novel photosensitizer, is turn-off of DNA synthesis in cells that have been irradiated in the presence of that photosensitizer.

Alternatively, survival of the target organism can be monitored by measuring the incorporation of [^{3}H] uracil into nucleic acids of the organism. This measurement can be made as described, for example, by McLeod and Remington (*J. Immunol. Meth.* 27:19-29, 1979). This assay can be used when the target organism is of the genus *Toxoplasma, e.g., T. gondii.*

If large numbers of candidates are to be screened it may be desirable to use a two-stage screen, wherein the first stage is an *in vitro* screen and the second stage employs cells.

A suitable positive control for photosensitizer activity is toluidine blue O.

2. The targeting moiety

The targeting moiety can be a molecule or a macromolecular structure that targets macrophages or that interacts with a pathogen. Thus, in some embodiments, the photosensitizer is also the targeting moiety. For example, some photosensitizers target macrophages directly (*see, e.g.,* Korbelik *et al., Cancer Res.* 51:2251-2255, 1991). Moieties, a target moiety alone or incorporated into a conjugate, can be a supramolecular structure (*e.g.,* a liposome, a micelle, a lipid vesicle, or the like) can be used to specifically target macrophages by certain receptors. Thus, a ligand for such receptors can be used as a targeting moiety. For example, the following receptors can be used to target macrophages: the complement receptor (Rieu *et al., J. Cell Biol.* 127:2081-2091, 1994), the scavenger receptor (Brasseur *et al., Photochem. Photobiol.* 69:345-352, 1999;

Suzuki *et al.*, *Nature* 386:292-296, 1997; Sarkar *et al.*, *Mol. Cell. Biochem.* 156:109-116, 1996), the transferrin receptor (Dreier *et al.*, *Bioconjug. Chem.* 9:482-489, 1998; Hamblin *et al.*, *J. Photochem. Photobiol.* 26:45-56, 1994; Clemens *et al.*, *J. Exp. Med.* 184:1349-1355, 1996), the Fc receptor (Rojanasakul *et al.*, *Pharm. Res.* 11:1731-1733, 1994; Harrison *et al.*, *Pharm Res.* 11:1110-4, 1994). The mannose receptor is particularly important for macrophage recognition of foreign material and has been used successfully to target molecules to macrophages (Frankel *et al.*, *Carbohydr. Res.* 300:251-258, 1997; Chakrabarty *et al.*, *J. Protozool.* 37:358-364, 1990; Mistry *et al.*, *Lancet* 348:1555-1559, 1996; Liang *et al.*, *Biochim. Biopys. Acta* 1279:227-234, 1996; Sarkar *et al.*, *Mol. Cell Biochem.* 156:109-116, 1996). Toll or toll-like receptors are also present on macrophages and are useful targets (Brightbill *et al.*, *Science* 285:732-736, 1999).

Moieties that can be conjugated with photosensitizers in order to target to macrophages include low density lipoproteins (Mankertz *et al.*, *Biochem. Biophys. Res. Commun.* 240:112-115, 1997; von Baeyer *et al.*, *Int. J. Clin. Pharmacol. Ther. Toxicol.* 31:382-386, 1993), very low density lipoproteins (Tabas *et al.*, *J. Cell Biol.* 115:1547-1560, 1991), mannose residues (as mentioned above) and other carbohydrate moieties (Pittet *et al.*, *Nucl. Med. Biol.* 22:355-365, 1995), poly-cationic molecules (*e.g.*, poly-L-lysine; Hamblin *et al.*, *J. Photochem. Photobiol.* 26:45-56, 1994), emulsions (Khopade *et al.*, *Pharmazie* 51:558-562, 1996), aggregated albumin (Hamblin *et al.*, *J. Photochem. Photobiol.* 26:45-56, 1994), biodegradable microspheres (Oettinger *et al.*, *J. Interferon Cytokine Res.* 19:33-40, 1999), non-biodegradable microspheres (Schroder, *Methods Enzymol* 112:116-128, 1985), nanoparticles (Lobenberg *et al.*, *AIDS Res. Hum. Retroviruses* 12:1709-1715, 1996);

Venier-Julienne *et al.*, *J. Drug Target.* 3:23-29, 1995; Schafer *et al.*, *J. Microencapsul.* 11:261-269, 1994; Gaspar *et al.*, *Ann. Trop. Med. Parasitol* 86:41-49, 1992), liposomes (Bakker-Woudenberg *et al. J. Drug Target.* 2:363-371, 1994; Meyers *et al.*, *Exp. Lung Res.* 19:1-19, 1993; Betageri *et al.*, *J. Pharm. Pharmacol.* 45:48-53, 1993; Muller *et al.*, *Biochim. Biophys. Acta.* 986:97-105, 1989; Kole *et al.*, *J. Infect. Dis.* 180:811-820, 1999), macrophage-specific cytokines (Biragyn *et al.*, *Nat. Biotechnol.* 17:253-258, 1999; Chan *et al.*, *Blood* 86:2732-2740, 1995), erythrocytes (Magnani *et al.*, *J. Leukoc. Biol.* 185:717-730, 1997), antibodies recognizing critical components of the tuberculous phagosome like Nrampl (Gruenheid *et al.*, *J. Exp. Med.* 185:717-730, 1997), α 2-macroglobulin (Chu *et al.*, *J. Immunol.* 152:1538-1545, 1994).

A targeting moiety can be directed to the infectious pathogen (*e.g.*, mycobacteria). For example, conjugates that couple relevant anti-mycobacterial antibiotics, such as isoniazid, to the photosensitizers can be used (Quenard *et al.*, *Biochemistry* 34:8235-8241, 1995). In addition, certain structural features of critical enzymes can be targeted, such as the hydrophobic pocket of the *Mycobacterium tuberculosis* enzyme inhA (Dessen *et al.*, *Science* 267:1638-1641, 1995). Alternatively, host molecules that target the bacteria, such as anti-microbial peptides (*e.g.*, granulysin), can be used in conjugates (Stenger *et al.*, *Science* 282:121-125, 1998).

A targeting moiety can be used alone or in combination, particularly to target both macrophages and the intracellular pathogen (*e.g.*, mycobacteria). Manipulations of the host cell can also complement the photosensitizer (Collins *et al.*, *J. Cell Sci.* 110:191-

200, 1997; Korbelik *et al.*, *Br. J. Cancer* 75:202-207, 1997; Krosl *et al.*, *Cancer Res.* 56:3281-3286, 1996).

The targeting moiety can be a polypeptide (which may be linear, branched, or cyclic). The targeting moiety can include a polypeptide having an affinity for a polysaccharide target, for example, a lectin (such as a seed, bean, root, bark, seaweed, fungal, bacterial, or invertebrate lectin). Particularly useful lectins include concanavalin A, which is obtained from jack beans, and lectins obtained from the lentil, *Lens culinaris*.

B. The Target Organism

An organism that is targeted for destruction by the methods and compositions described herein is an unwanted organism; unwanted in that it infects a host organism (or a cell thereof) and causes or aggravates a disease or disorder in that host. Especially preferred target organisms are bacterial cells, particularly of the genera *Mycobacteria* and *Toxoplasma*, and viruses.

Organisms to be targeted by the compositions and methods of the present invention can be found on any light-accessible surfaces or in light-accessible areas, for example, in human and animal subjects, materials to be decontaminated, or on crop plants. In the cases of humans and animals, infections of the epidermis, oral cavity, nasal cavity, sinuses, ears, lungs, urogenital tract, and gastrointestinal tract are light accessible. Epidermal infections include those of unwanted organisms of bacterial, fungal, viral and animal origin, and include subcutaneous infections, especially localized lesions, for example caused by protozoans, parasites, or parasitic mites, which infections are light-accessible. Infections of the peritoneal cavity, such as those resulting from burst appendicitis, are light accessible

via at least laparoscopic devices. A variety of skin infections which are refractory to antibiotics or long-term antifungal treatment, for example, dermatophycoses of the toenail, are suitable for photodynamic therapy using the methods and compositions of the invention.

Lung infection can occur with a variety of bacterial genera and species, which include the classical tuberculosis of *Mycobacterium tuberculosis*, the pseudomonads, which are the primary cause of death of cystic fibrosis patients, *Klebsiella*, and can also occur with a variety of virus strains. A variety of fungi and parasites are opportunistic pathogens of the lung, and *Pneumocystis carinii* infection is a common cause of death in immunocompromised AIDS patients. As pathogens of the lung are increasingly resistant to classical antibiotic therapies, photodynamic therapy with the compositions of the instant invention offer an alternative method for eliminating these unwanted organisms that is independent of the microbial mechanisms of resistance.

C. Administering the Molecular Conjugates of the Invention to a Host Organism

When a photosensitizer is linked to a targeting moiety, the resulting conjugate should be soluble under physiological conditions, in aqueous solvents containing appropriate carriers or excipients, or in other systems, such as liposomes, that may be used to administer the conjugate to a subject.

The molecular conjugates of the invention can be delivered to a subject in a free form, *i.e.*, as a conjugate in solution. Alternatively the conjugates can be delivered in various formulations including, but not limited to, liposome, peptide-bound, polymer-bound, or detergent-containing formulations. Those of ordinary

skill in the art are well able to generate and administer such formulations (see also, below).

The conjugates of the invention should be stable during the course of at least a single round of treatment by continuous or pulsed irradiation, during which the photosensitizer within the conjugate would, preferably, be repeatedly excited to the energized state, undergoing multiple rounds of generation of singlet oxygen.

The compounds of the invention include conjugate molecules that have been formulated for topical administration, and also for administration to various external organs such as the outer ear, or organs accessible by external administration, such as by oral application or by lavage of the lung. The examples mentioned here are not intended as limiting with respect to the nature of the conjugate photosensitizer compositions of the invention, or to a particular route of the administration, and additional routes are listed herein. In another embodiment of the present invention, the photosensitizer compositions can be administered by combination therapy, *i.e.*, combined with other agents. For example, the combination therapy can include a composition of the present invention with at least one other photosensitizer, at least one antibiotic, or other conventional therapy.

Photosensitizer conjugates that are somewhat insoluble in an aqueous solvent can be applied in a liposome, or a time release fashion, such that illumination can be applied intermittently using a regimen of periods of illumination alternating with periods of non-illumination. Other regimens contemplated are continuous periods of lower level illumination, for which a time-release formulation is suitable.

As used herein, the phrase "pharmaceutically acceptable carrier" includes any and all solvents,

dispersion media, coatings, antibacterial and antifungal agents, isotonic and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like that are physiologically compatible. The use of such media and agents for pharmaceutically active substances is well known in the art. Preferably, the carrier is suitable for oral, intravenous, intramuscular, subcutaneous, parenteral, spinal or epidermal administration (*e.g.*, by injection or infusion). Depending on the route of administration, the active compound may be coated in a material to protect the compound from the action of acids and other natural conditions that may inactivate the compound.

Conjugates of the invention can also be administered parenterally. The phrase "administered parenterally" as used herein means modes of administration other than oral administration, usually by injection, and includes, without limitation, intravenous, intramuscular, intraarterial, intrathecal, intracapsular, intraorbital, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal, epidural and intrasternal injection and infusion.

A composition of the present invention can be administered by a variety of methods known in the art. As will be appreciated by the skilled artisan, the route and mode of administration will vary depending upon the desired results. The active compounds can be prepared with carriers that will protect the compound against rapid release, such as a controlled release formulation, including implants, transdermal patches, and microencapsulated delivery systems. Biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid,

collagen, polyorthoesters, and polylactic acid. Many methods for the preparation of such formulations are patented or generally known to those skilled in the art. See, *e.g.*, *Sustained and Controlled Release Drug Delivery Systems*, J.R. Robinson, ed., Marcel Dekker, Inc., New York, 1978.

Dosage regimens are adjusted to provide the optimum desired response (*e.g.*, a therapeutic response). For example, a single bolus may be administered, several divided doses may be administered over time, or the dose may be proportionally reduced or increased as indicated by the exigencies of the therapeutic situation.

One of ordinary skill in the art can determine and prescribe the effective amount of the pharmaceutical composition required. For example, one could start doses of the known or novel photosensitizer composition levels lower than that required in order to achieve the desired therapeutic effect and gradually increase the dosage until the desired effect is achieved.

Irradiation of the appropriate wavelength for a given compound may be administered by a variety of wavelengths. Methods for irradiation include, but are not limited to, the administration of laser, nonlaser, or broad band light. Irradiation can be produced by extracorporeal or intraarticular generation of light of the appropriate wavelength. Light used in the invention may be administered using any device capable of delivering the requisite power of light including, but not limited to, fiber optic instruments, arthroscopic instruments, or instruments that provide transillumination. Delivery of the light to a recessed, or otherwise inaccessible physiological location can be facilitated by flexible fiber optics (implicit in this statement is the idea that one can irradiate either a broad field, such as the lung or a lobe of the lung, or a

narrow field where bacterial cells may have localized). The source of the light needed to inactivate the bacteria can be an inexpensive diode laser or a non-coherent light source.

EXAMPLES

The studies that follow were performed with *Mycobacterium bovis* BCG that was grown in liquid culture (7H9 medium), incubated with a photodynamic compound, aliquoted into the wells of a 96-well tissue culture plate and exposed to light (for one hour at 80 J/cm). (Control experiments are described below). To assess the effect of this treatment on cytotoxicity, the bacteria, in suspension, were diluted by ten-fold dilutions, and 10 μl aliquots were spotted onto agar plates (7H10 medium). The number of colony forming units (CFUs) were counted 7-10 days later.

More specifically, for each photodynamic compound tested, 100 μl of a liquid *M. bovis* culture (OD_{600} = 1) was transferred to an Eppendorf tube, which was centrifuged to pellet the bacterial cells. The medium was then discarded and the cells were resuspended in either 1 ml of medium or 1 ml of 7H9 broth. The resulting concentration of cells was approximately 1 x 10^6 cells/ml. Once resuspended, the photodynamic compound (or, as a control, an equivalent volume of PBS) was added to the cell suspension. The following photodynamic compounds were tested in this study: pl-ce6, BPD, and cpd 33.

The cells were incubated with the photodynamic compounds and then aliquoted (in 200 μl aliquots) onto a microtiter plate, in duplicate. The first set of samples was exposed to light (for one hour at 80 J/cm), but the duplicate set remained in the dark. Each sample was then serially diluted and 10 μl of each dilution was spotted,

in triplicate, onto a mycobacterial agar plate. The plates were allowed to dry and then incubated for 7-10 days at 37°C. At the conclusion of the incubation period, colony forming units were counted.

The results obtained are shown in Fig. 1. The number of CFUs was clearly reduced in all samples that were incubated with a photodynamic compound and exposed to light (L; D = dark) except for the sample incubated with cpd33 (which was toxic to BCG regardless of whether or not the cells were exposed to light (data not shown). While only modest cytotoxicity was evident in the samples treated with pl-ce6-PEG and BPD "non-liposomal," these compounds reduced the size of the colonies that were formed and altered their morphology.

The study described above was repeated and the results were analyzed in terms of the number of cells killed relative to the apparent uptake of the photodynamic compound. These data are shown in Figs. 2A and 2B and the relative phototoxicity of the compounds is shown in Fig. 2C.

Other Embodiments

Other embodiments are described in the text that is appended to, and part of, the specification. The present invention is not to be limited in scope by the specific embodiments described, which are intended as single illustrations of individual aspects of the invention. Functionally equivalent methods and compositions are within the scope of the invention, and will become apparent to those skilled in the art from the foregoing description. Such functional equivalents are intended to fall within the scope of the appended claims.

What is claimed is:

Claims

1. A method for treating a subject having a disorder associated with an intracellular pathogen, the method comprising administering to the subject a molecular conjugate comprising

(a) a photosensitizer and

(b) a targeting moiety, wherein the targeting moiety targets the conjugate to the intracellular pathogen or to an infected host cell.

2. The method of claim 1, wherein the intracellular pathogen is a bacterial cell.

3. The method of claim 2, wherein the bacterial cell is a mycobacterium.

4. The method of claim 3, wherein the mycobacterium is *Mycobacterium tuberculosis*.

5. The method of claim 1, wherein the intracellular pathogen is within a phagocyte.

6. The method of claim 5, wherein the phagocyte is a macrophage.

7. The method of claim 1, wherein the intracellular pathogen is within a vacuole, vesicle, or organelle of a cell of the subject.

8. The method of claim 1, wherein the disorder is an active disorder.

9. The method of claim 1, wherein the disorder is a latent disorder.

10. The method of claim 1, wherein the disorder is a disease selected from the group consisting of tuberculosis, leprosy, MAI complex infection in AIDS patients associated with *Mycobacterium avium*, leishmaniasis and toxoplasmosis.

11. The method of claim 1, further comprising diagnosing the subject as having a disorder associated with an intracellular pathogen.

12. The method of claim 11, wherein the disorder is a latent disorder.

13. The method of claim 1, further comprising irradiating the subject, the irradiation having a wavelength that causes the photosensitizer to produce a cytotoxic effect.

14. The method of claim 13, wherein the source of the irradiation is a laser.

15. The method of claim 1, wherein the molecular conjugate is administered to the subject by intravenous administration.

16. The method of claim 1, wherein the molecular conjugate is administered to the subject by parenteral administration.

17. The method of claim 16, wherein the parenteral administration comprises topical administration.

18. The method of claim 1, wherein the photosensitizer is a porphyrin or an active derivative thereof.

19. The method of claim 18, wherein the porphyrin is chlorin e6.

20. The method of claim 1, wherein the targeting moiety targets macrophages directly.

21. The method of claim 20, wherein the targeting moiety targets a complement receptor, a scavenger receptor, a transferrin receptor, an Fc receptor, a mannose receptor or a toll or toll-like receptor.

22. The method of claim 1, wherein the polypeptide is a serum albumin.

23. The method of claim 1, wherein the targeting moiety is a low density lipoprotein, a very low density lipoprotein, a mannose residue, poly-L-lysine, or albumin.

24. The method of claim 1, wherein the molecular conjugate is administered to the subject at least twice.

25. A molecular conjugate comprising

(a) a photosensitizer and

(b) a targeting moiety, wherein the targeting moiety targets the conjugate to an intracellular pathogen or to an infected host cell.

26. A method for treating a subject having tuberculosis, the method comprising administering to the subject a molecular conjugate comprising

(a) a photosensitizer and

(b) a targeting moiety, wherein the targeting moiety targets the conjugate to a *Mycobacterium tuberculosis* cell.

27. The method of claim 26, wherein the tuberculosis is active.

28. The method of claim 26, wherein the tuberculosis is latent.

29. The method of claim 26, further comprising irradiating the lung.

30. A method of killing a bacterial cell, the method comprising contacting the cell with pl-ce6 or BPD.

31. The method of claim 30, further comprising irradiating the bacterial cell that has been contacted with pl-ce6 or BPD.

32. The method of claim 30, wherein the bacterial cell is a mycobacterial cell.

33. A method for treating a subject having a disorder associated with an intracellular pathogen, the method comprising administering to the subject: (1) an antibiotic and (2) a molecular conjugate comprising

(a) a photosensitizer and

(b) a targeting moiety, wherein the targeting moiety targets the conjugate to the intracellular pathogen or to an infected host cell.

34. The method of claim 33, wherein the molecular conjugate is administered before the antibiotic is administered.

35. The method of claim 33, wherein the intracellular pathogen is a bacterial cell.

36. The method of claim 35, wherein the bacterial cell is a mycobacterium.

37. The method of claim 36, wherein the mycobacterium is *Mycobacterium tuberculosis*.

38. The method of claim 33, wherein the intracellular pathogen is within a phagocyte.

39. The method of claim 38, wherein the phagocyte is a macrophage.

40. The method of claim 33, further comprising irradiating the subject, the irradiation having a wavelength that causes the photosensitizer to produce a cytotoxic effect.

41. The method of claim 40, wherein the source of the irradiation is a laser.

42. A method for killing a Mycobacterial cell, the method comprising:

(a) contacting the cell with a molecular conjugate comprising a photosensitizer; and

(b) irradiating the cell, wherein the irradiation has a wavelength that causes the photosensitizer to produce a cytotoxic effect.

43. The method of claim 42, wherein the molecular conjugate further comprises a targeting moiety that targets the conjugate to an infectious agent.

44. The method of claim 42, wherein the photosensitizer is a porphyrin or an active derivative thereof.

45. A method of treating a subject having an infectious disease of the lung, the method comprising:

(a) administering to the subject a molecular conjugate comprising a photosensitizer; and

(b) irradiating the lung, wherein the irradiation has a wavelength that causes the photosensitizer to produce a cytotoxic effect.

46. The method of claim 45, wherein the molecular conjugate further comprises a targeting moiety that targets the conjugate to an infectious agent.

47. The method of claim 45, wherein the photosensitizer is a porphyrin or an active derivative thereof.

48. The method of claim 45, wherein the infectious disease of the lung is associated with a bacterial infection.

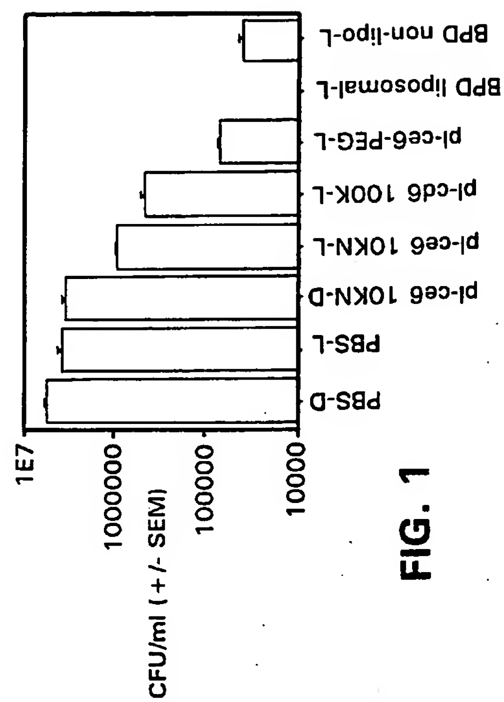
49. The method of claim 48, wherein the bacterial infection is associated with a *Mycobacterium*.

50. The method of claim 45, wherein the irradiation of the lung is provided by a light source introduced into the passages through which air is inhaled.

51. The method of claim 45, wherein the irradiation of the lung is provided by a light source introduced through the chest wall.

52. The method of claim 45, wherein irradiation of the lung is directed to the base of the lung.

53. The method of claim 45, wherein irradiation of the lung is directed to the apex of the lung.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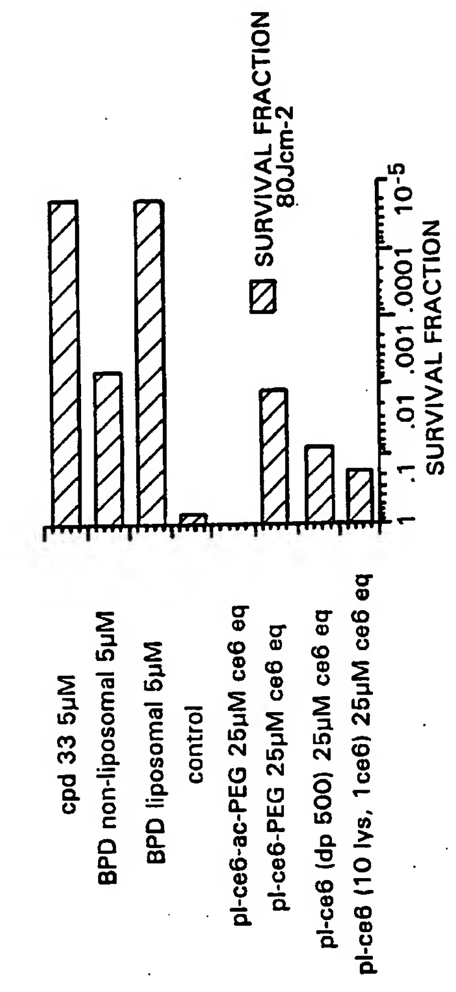
1E7
1000000
100000
10000
PBS-D
PBS-L
pl-ce6 10KN-D
pl-ce6 10KN-L
pl-cd6 100K-L
pl-ce6-PEG-L
BPD liposomal-L
BPD non-lipo-L

FIG. 1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BPD non-liposomal 5µM
BPD liposomal 5µM
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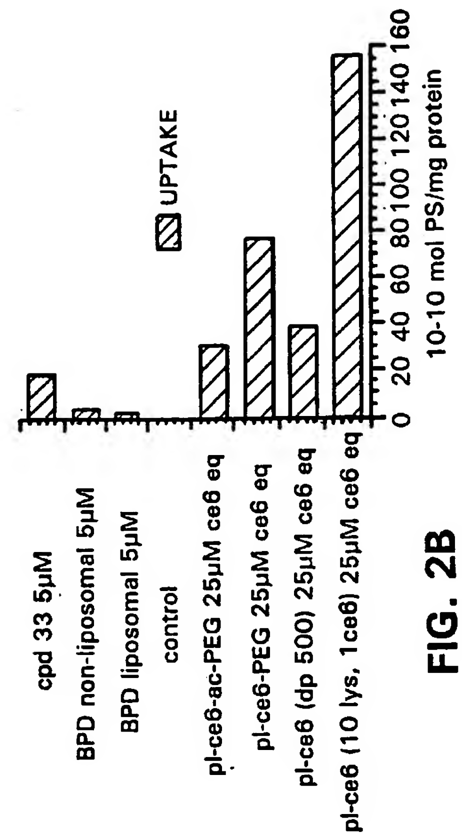
pl-ce6-PEG 25µM ce6 eq
pl-ce6 (dp 500) 25µM ce6 eq
pl-ce6 (10 lys, 1ce6) 25µM ce6 eq
1 .1 .01 .001 .0001 10-5
SURVIVAL FRACTION

FIG. 2A


UPTAKE
cpd 33 5µM
BPD non-liposomal 5µM
BPD liposomal 5µM
control
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pl-ce6-PEG 25µM ce6 eq
pl-ce6 (dp 500) 25µM ce6 eq
pl-ce6 (10 lys, 1ce6) 25µM ce6 eq
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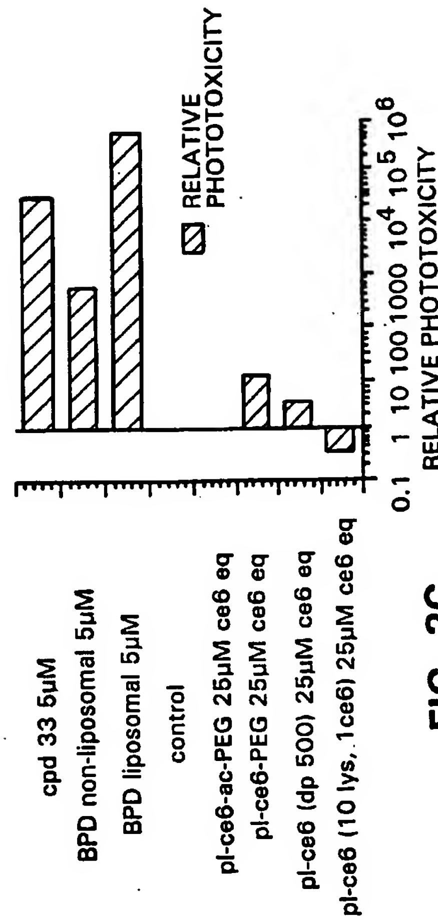
10-10 mol PS/mg protein

FIG. 2B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BPD non-liposomal 5µM
BPD liposomal 5µM
control
pl-ce6-ac-PEG 25µM ce6 eq
pl-ce6-PEG 25µM ce6 eq
pl-ce6 (dp 500) 25µM ce6 eq
pl-ce6 (10 lys, 1ce6) 25µM ce6 eq
RELATIVE PHOTOTOXICITY
0.1 1 10 100 1000 10^4 10^5 10^6
RELATIVE PHOTOTOXICITY

FIG. 2C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/24124

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :A61K 49/00, 38/00; A01N 37/18; C12N 1/20
US CL : 424/9.2, 9.362, 9.61; 514/2; 435/243
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 424/9.2, 9.362, 9.61; 514/2; 435/243

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST, STN, MEDLINE, CAPLUS, terms, photosensitizer, cytotoxic, porphyrin, chlorine, Mycobacteria, tuberculosis, leprosy.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,091,385 A (GULLIYA et al) 25 February 1992 (25.02.92), see abstract.	1-53
X	US 5,512,675 A (TANG et al) 30 Apri 1996 (30.04.96), see abstract and use.	1-53
Y	US 5,389,378 A (MADDEN) 14 February 1995 (14.02.95), see abstract and Claim 1.	1-53
Y	US 5,332,567 A (GOLDENBERG) 26 July 1994 (26.07.94), see abstract and Anti-bacterial MAbs.	1-53

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 JANUARY 2000	15 FEB 2000

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	LI LEE Jerry J. Dey for
Facsimile No. (703) 305-3230	Telephone No. (703) 308-0196